ELSEVIER

Microelectronics Journal 39 (2008) 1268–1269

Microelectronics Journal

www.elsevier.com/locate/mejo

Localized modes in superconductor–dielectric photonic crystals with broken translational symmetry ☆

G.B. Orozco[a,*], J.C. Granada[b]

[a] Universidad San Buenaventura, Cali. Fac. de Ingenierías, AA 25162, Cali, Colombia
[b] Departamento de Física, Universidad del Valle, AA 25360, Cali, Colombia

Available online 15 May 2008

Abstract

On the basis of the linear response theory, we calculate the components of the electromagnetic propagator of a non-magnetic system, consisting of alternating superconductor–dielectric slabs of different thicknesses in the case when one of the layers breaks the translational symmetry. The photonic band structure and the corresponding power spectra are studied from the poles and the imaginary part of the electromagnetic propagator. It is shown that as the magnitude of the in-plane wave vector rises, the frequency of the lowest localized mode increases and the highest-frequency localized mode decreases. On the other hand, for a fixed in-plane wave vector it is shown that there appear additional modes in the band gap.
© 2008 Elsevier Ltd. All rights reserved.

PACS: 42.55.Tv; 42.70.Qs

Keywords: Photonic crystals; Photonic band gap; Superconductor materials and optic materials

During the last years an explosion of research in the design and fabrication of photonic crystals [1] with complete photonic band gap has inspired a wealth of potential telecommunication applications, including waveguides, channel drop filters, and omni-directional reflectors. In particular, the modes arising in a photonic crystal consisting in a binary system of polar rods immersed in a homogeneous dielectric medium were considered [2]. In the case of photonic crystals containing superconductor slabs [3,4], a low-frequency plasma gap exists associated with the non-zero density of superconductor carriers, and there is a photon-superelectron hybrid mode around the polariton gap. In the present communication, we consider a superconductor–dielectric multilayer structure with an infinite number of periods and a single structural defect. The unit cell of thickness d of the multilayered system consists of a superconducting slab of thickness d_1 (with relative dielectric permittivity ε_1 below) and a dielectric slab of thickness d_2 (with relative dielectric permittivity ε_2); the structural defect is considered as a superconducting slab of thickness d_d and relative dielectric permittivity ε_d. If a *TE* wave with frequency ω and wave vector $\mathbf{k}$ propagates in such a system, the superconductor slabs can be characterized by a relative dielectric permittivity of the form $\varepsilon_a(\omega) = 1 - [c/(\omega\lambda_{La})]^2$, where $a = 1, 2, d$, $\lambda_{La}(T) = \lambda_{0a}[1-(T/Tc)^4]^{1/2}$, $\lambda_0 = [mc^2/4\pi n_a e^2]^{1/2}$ (n_a is the density of superconductor carriers at the ath slab). On the basis of the linear response theory we can calculate the components of the electromagnetic propagator $g_{ik}(\mathbf{k}, \omega; z, z')$. For the particular case of the xx components of the Green tensor, we can write $g^{(m)}_{(i)Lxx}(\kappa_i, \omega; z) = f(a_{Li}, b_{Li}, \kappa_i, z - d_i/2)\exp(-qd)$, $(0 < z < d_i)$, $g_{dxx}(\kappa, \omega; z) = f(a_d, b_d, \kappa_d, z - d/2) + 4\pi[(c^2\kappa_d^2/\omega^2\varepsilon_d)]\exp(-k_d|z - z'|)$, $(0 < z < d_d)$, $g^{(m)}_{(i)Rxx}(\kappa_i, \omega; z) = f(a_{Ri}, b_{Ri}, \kappa_i, z - d_i/2)\exp(-qd)$, $(0 < z < d_i)$, $i = 1, 2$; $m = 1, 2, \ldots$, where qd is the decay factor, $f(a, b, \omega, z) = a\exp(\kappa z) + b\exp(-\kappa z)$, $\kappa_i = (k^2 - \varepsilon_i\omega^2/c^2)^{1/2}$.

☆ This work is part of the research project "Localized modes in magnetic active photonic crystals with structural defects (third phase)", which is supported by Universidad San Buenaventura-Cali.

*Corresponding author.
E-mail addresses: gbecerra@usb.edu.co (G.B. Orozco), granada@univalle.edu.co (J.C. Granada).

0026-2692/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mejo.2008.01.012

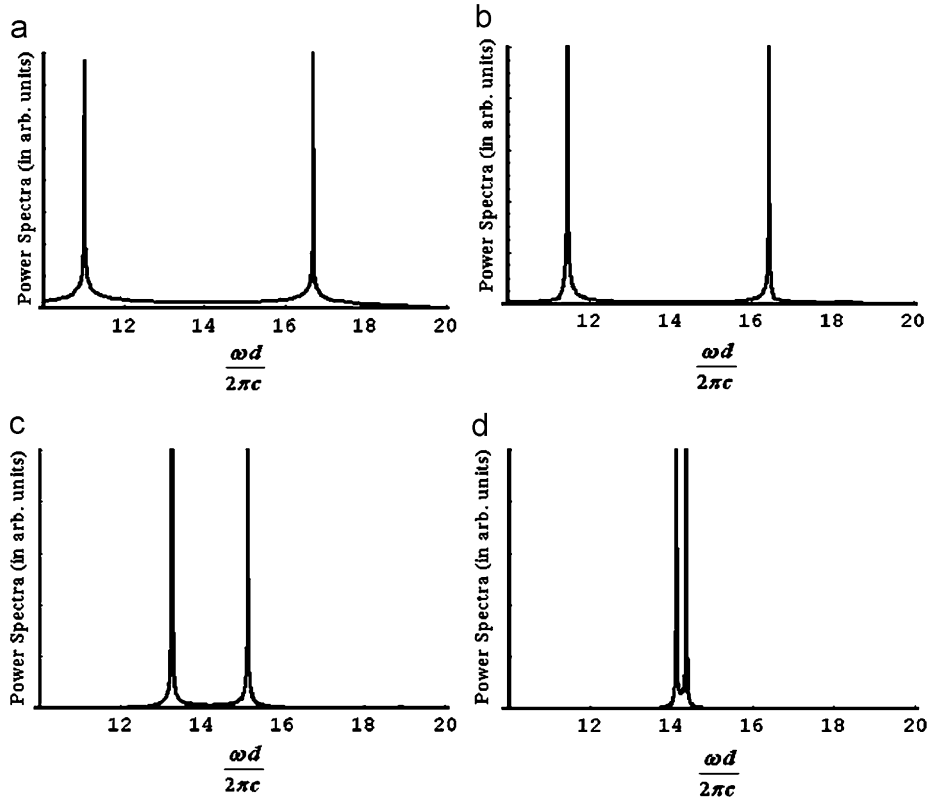

Fig. 1. Power spectra of local modes in a 1D photonic crystal with a single defect layer: $\varepsilon_2 = 1$, $\Lambda = 0.05$; $d_1 = 0.3$; $d_2 = 1 - d_1$; $\Lambda_d = 0.3$; $d_d = 0.8d_1$. (a) $k_d = 0.1$; (b) $k_d = 0.25$; (c) $k_d = 0.5$; (d) $k_d = 1$.

By imposing the continuity of g_{xx} and $[(\varepsilon/\kappa^2)dg_{xx}/dz]$ at the interfaces, we obtain the following relations:

$$|L_1\rangle = \hat{Q}|R_1\rangle + K\mathrm{e}^{-k_d z'}(\hat{R}|d_+\rangle - \hat{R}_1|d_-\rangle), \quad (1)$$

$$|D\rangle = K\mathrm{e}^{-k_d z'}(\hat{R}_2|d_+\rangle - \hat{R}_3|td_-\rangle), \quad (2)$$

and $(\hat{I} - \hat{P}\mathrm{e}^{-qd})|L_1\rangle = 0$, $(\hat{I} - \hat{P}\mathrm{e}^{qd})|R_1\rangle = 0$.

Here $\langle L_1| = (a_{L1}\ b_{L1})$, $\langle R_1| = (a_{R1}\ b_{R1})$, $\langle D| = (a_d\ b_d)$, $\langle d_\pm| = (1 \pm \varepsilon_d/k_d)$, $K = (4\pi\omega^2/c^2\varepsilon_d)$, $\hat{P} = \hat{T}^{-1}(k_1, d_1)\hat{T}(k_2, -d_2) \times \hat{T}^{-1}(k_2, d_2)\hat{T}(k_1, -d_1)$, $\hat{Q} = \hat{T}^{-1}(k_1, d_1)\hat{T}(k_d, -d_d) \times \hat{T}^{-1}(k_d, d_d)\hat{T}(k_1, -d_1)$, $\hat{R} = \hat{T}^{-1}(k_1, d_1)\hat{T}(k_d, -d_d) \times \hat{T}(k_d, -d_d)$, $\hat{R}_1 = \hat{T}^{-1}(k_1, d_1)$, $\hat{R}_2 = \hat{T}^{-1}(\varepsilon k_d, d_d) \times [\hat{T}(k_1, -d_1)\hat{Q}^{-1}\hat{R} - \hat{I}]$, $\hat{R}_3 = \hat{T}^{-1}(k_d, d_d)\hat{T}(k_1, -d_1) \times \hat{Q}^{-1}\hat{T}^{-1}(k_1, d_1)$, $\hat{T}_{11}(k_i, d_i) = f_i$, $\hat{T}_{12}(k_i, d_i) = f_i g_i$, $\hat{T}_{21}(k_i, d_i) = 1/f_i$, $\hat{T}_{22}(k_i, d_i) = -1/f_i g_i$, $f_i = \exp(k_i d_i/2)$, $g_i = \varepsilon_i/k_i$. For the description of the localized modes, let us introduce the dimensionless quantities $\Omega = \omega d/(2\pi c)$, $\Lambda = d/(2\pi\lambda_L)$. The bulk spectra of collective excitations consists of a low-frequency band (with frequencies in the range $0 < \omega < \omega_0$, $\omega_0 < c/\lambda L$) and a narrow high-frequency band with frequencies $\omega > c/\lambda_L$, the bands being separated by a band gap. In Fig. 1 we have plotted the power spectra of the localized modes arising in the described system. For the numerical calculations we have taken the values $\varepsilon_2 = 1$, $\Lambda = 0.05$; $d_1 = 0.3d$; $d_2 = d - d_1$; $\Lambda_d = 0.3$; $d_d = 0.8d_1$. For this set of parameters there are two modes with frequencies lying inside the band gap. As the magnitude of the in-plane wave vector rises, the frequency of the lowest mode increases and the high-frequency mode decreases. For $ka > 1$ these modes are degenerate and tend to the frequency corresponding to the center (in-phase oscillations) of the lowest frequency band of the ideal system. The behavior of the corresponding decay factor qd shows that as the in-plane vector k increases, the localization length increases and becomes large at great values of k. These results can be extended in order to consider local modes in a system with a polariton gap, as those described in [2].

References

[1] E. Istrate, E.H. Sargent, Rev. Mod. Phys. 78 (2006) 455.
[2] K.C. Huang, et al., Phys. Rev. B 68 (2003) 075209.
[3] H. Takeda, et al., Phys. Rev. B 70 (2004) 085109.
[4] C.-J. Wua, et al., Physica C 432 (2005) 133.